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ABSTRACT

Since the 1999 fall semester, the TI-92 Plus or the TI-89 has been a compulsory purchase for new students entering one engineering school in Montreal, Canada (almost 1000 enrolments a year). The purpose of this paper is to share impressions of a campus-wide experience and to communicate solutions adopted to help students and faculty members in the use of these calculators. (MM)

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Help in using Symbolic, Hand-held Calculators in Teaching Engineering Mathematics

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Since the 1999 fall semester, the TI-92 Plus or the TI-89 has been a compulsory purchase for new students entering our engineering school (almost 1000 enrolments a year). The purpose of this paper is to share our impressions of this campus-wide experience and to communicate the solutions that we considered and adopted to help students and faculty members in the use of these calculators.

Introduction

To give you a perspective of our working environment, we teach undergraduate level courses at the École de technologie supérieure (ETS) in Montréal. It is a French technical engineering school where undergraduate student enrolment stands at approximately 2500.

Since the 1999 fall semester, the TI-92 Plus or the TI-89 has been compulsory for all new full-time students entering our engineering school. Both models offer the same symbolic computation capabilities; they differ mainly by their physical shape and size. Students learn to use their calculators during their first mathematics course, calculus.

The symbolic and algebraic computation capabilities of these machines have naturally brought us to question and change the *what* and the *how* we teach mathematics. Students now have a tool that can do in a few seconds what would take much longer when done manually. For example, there is quite a bit of calculation involved in the decomposition of this rational function into partial fractions.

$$\frac{t^3 - t + 1}{(t+5)(t+2)^2\left(t^2+4\right)} = \frac{-\frac{119}{261}}{t+5} + \frac{\frac{61}{144}}{t+2} + \frac{-\frac{5}{24}}{(t+2)^2} + \frac{\frac{15}{464}t - \frac{13}{58}}{t^2+4}$$

The concept of decomposition is simple enough, it is the amount of algebraic manipulations required that is time-consuming. We consider that once students have understood a concept, and that the subject can benefit from it, long and tedious manual calculations are better left to the calculator. This gives us extra time for the deeper exploration and understanding of the concept. Incidentally, new topics come up naturally when using these calculators. For example, see screen 1, when students are asked to input the function $e^t + e^{-t}$ into the calculator[1] they look to us for an explanation.

[1] Our students do not usually know about hyperbolic functions beforehand.

July 9, 2001

G. Picard

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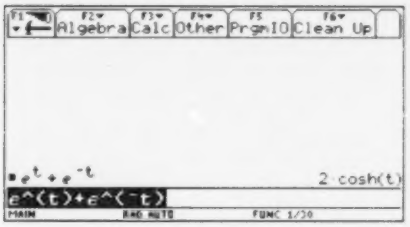
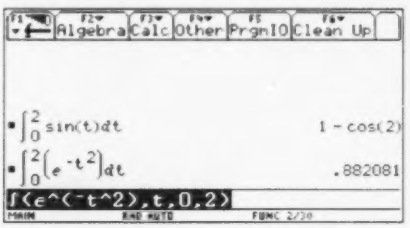


screen 1

An in-class example

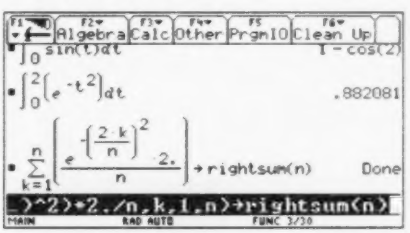
To illustrate how our lectures have changed with the introduction of these calculators, here is an example of one of our presentations. It is part of a 90-minute lecture.

When presenting the second fundamental theorem of calculus, we start by reviewing the first fundamental theorem of calculus, using the TI's computation capabilities. We know that when an anti-derivative of the function we wish to integrate is found, we can evaluate it at the upper and lower limits to get an exact answer. This is also what the calculator does; see the first line of screen 2. However, if no anti-derivative in terms of elementary functions exists or can be found, we must estimate the definite integral's value by approximation. This is also what the calculator does; see the second line of screen 2.



screen 2

We use this opportunity to review Riemann right-hand and/or left-hand sums by having the students program these sums on their machines; see screen 3.



screen 3

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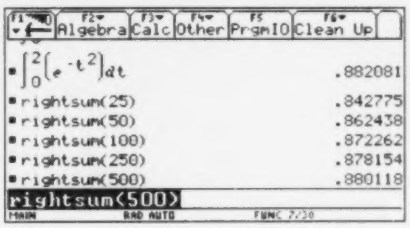
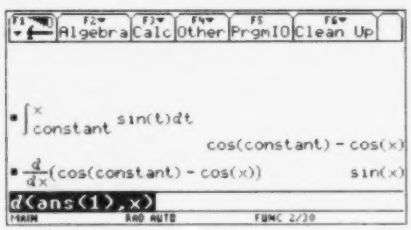
Now that all our students have their own TI, the computation of Riemann sums that was once long and tedious, is now quick and easy. Students cannot hide from the mathematical notation when using these calculators. They develop a better understanding of the mathematical notation involved because they have to use it! Also, when asked to evaluate such sums for different values of n, with n being the number of subintervals, they are always happy to shout out their answers. We can take down their answers to build a table of values for the different values of n. It is easy to see that the constructed sequence converges to the value of the definite integral we are looking for; see screen 4.



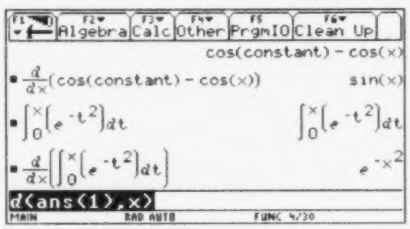
screen 4

After reviewing the 1st fundamental theorem of calculus we introduce the 2nd, which states that the derivative of a definite integral with respect to its upper limit is the integrand at the upper limit. We start by performing the necessary calculations on the blackboard so students can understand the algebraic meaning of the 2nd fundamental theorem of calculus. Once this has been done, we can use the TI's symbolic computation capabilities to further develop their understanding of the theorem.

When there exists an anti-derivative in terms of elementary functions, such as for $\sin(t)$, the TI performs the same type of calculations that we do manually; see screen 5.


F1 F2 Algebra F3 Calc F4 Other F5 PrgmIO F6 Clean Up
$\int_{\text{constant}}^{x} \sin(t)\,dt$
cos(constant) - cos(x)
$\frac{d}{dx}(\cos(\text{constant}) - \cos(x))$ sin(x)
d(ans(1),x)
MAIN RAD AUTO FUNC 2/30

screen 5


F1 F2 Algebra F3 Calc F4 Other F5 PrgmIO F6 Clean Up
cos(constant) - cos(x)
$\frac{d}{dx}(\cos(\text{constant}) - \cos(x))$ sin(x)
$\int_0^x \left(e^{-t^2}\right) dt$ $\int_0^x \left(e^{-t^2}\right) dt$
$\frac{d}{dx}\left(\int_0^x \left(e^{-t^2}\right) dt\right)$ e^{-x^2}
d(ans(1),x)
MAIN RAD AUTO FUNC 4/30

screen 6

On the other hand, when no anti-derivative in terms of elementary functions exists, such as for the Gaussian curve, the TI simply rewrites the integral; see screen 6. Since the definite integral

$$\int_0^x e^{-t^2}\,dt$$

is a function of x, the upper limit, we can expect it to have a derivative.

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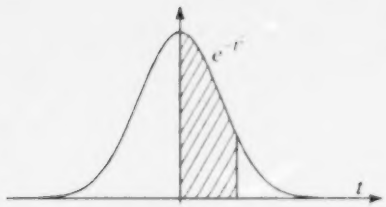


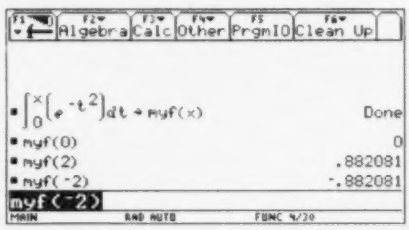
figure 1

By using the TI to compare what happens to the two different types of functions, one that has a simple anti-derivative and one that does not, we can easily put the emphasis on the fact that we don't need to find the anti-derivative to use the theorem, as illustrated on screen 6.

Many students have difficulties with functions and functional notation. With symbolic computation capabilities at hand, we can easily explore with our students, and in our classroom, the properties of the function defined as the following definite integral:

$$myf(x) = \int_0^x e^{-t^2}\,dt\,.$$

We start by defining the integral as *myf*(*x*) on the calculator, see screen 7, and ask students to use figure 1 to find *myf*(0) and only then, compare their answer with the TI's. We also have them confirm the earlier limit of Riemann sums by evaluating *myf*(2) and have them notice the busy signal that comes up on the calculator. The fact that it takes the machine a few seconds to evaluate *myf*(2) gives us the opportunity to remind students that it is proceeding by numerical approximation. Students get a better understanding of what is going on because they went through the approximation process beforehand. Finally, we also have students evaluate *myf*(-2) directly on the TI, expecting the same kind of answer as *myf*(2), and ask them to explain why the answer is negative.



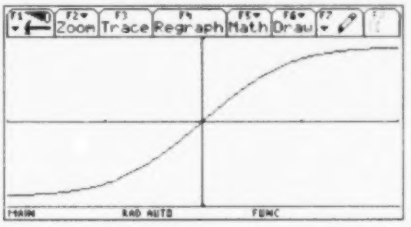
screen 7

The next natural step is to graph *myf*(*x*). This can take some time on the TI. While the machine is evaluating and connecting the dots, we turn to the blackboard and figure out what the graph should look like. We know, by the 2nd fundamental theorem of calculus, that $myf'(x) = e^{-x^2}$. We can easily show

that $myf'(x) > 0$, $\forall x \in \mathbb{R}$, and that $\lim_{x \to \pm\infty} myf'(x) = 0$. Therefore $myf(x)$ is increasing and, as x moves away from the origin, the curve flattens out. Also, since

$$myf''(x) = -2xe^{-x^2},$$

$myf(x)$ will be concave up when $x < 0$, concave down when $x > 0$, and there will be a point of inflexion at $x=0$. We take advantage of the TI's busy signals to answer student questions.



screen 8

The graphing process would be quicker on a computer. We used to use Maple or Derive, but students were passive in front of the display. We made the symbolic calculator compulsory because we want our students to use it in the classroom. We want all our students to actively participate in this process on their own calculator. As they try things, they tend to ask more questions and are generally more interested in what is happening. They also seem to have a better overall understanding of the material. The price we they pay is that students develop less algebraic virtuosity. It is a price we are willing to pay to be able to tackle more challenging problems. Finally, it must be noted that we still have students use CAS (Computer Algebra Systems) on computers when printouts are needed or when the problems are better explored with more powerful computing tools.

Mandatory calculators

Implementing the mandatory use of the TI-89/92 Plus calculators in the fall of 1999 wasn't an easy task. We had to make sure that the appropriate equipment was available and that all instructors were capable of using this equipment.

We realized that there were few resources available in French, on the web, to support the use of these calculators. Following our experience, in the summer 2000, we collected questions that students or instructors often asked us about the use of these calculators. We then designed (with the assistance of two colleagues, Michel Beaudin and Chantal Trottier) the web site http://www.seg.etsmtl.ca/ti/, which provides quick and easy access to information on the use of these calculators. Its guided tour, FAQ, and

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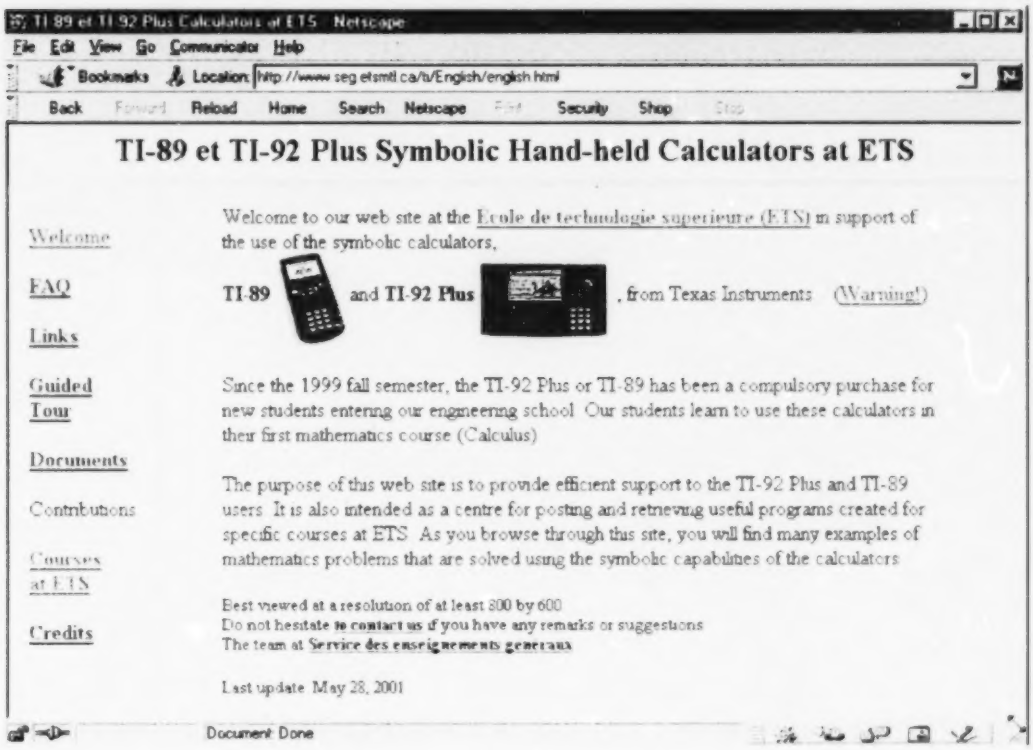
different documents were designed to meet the specific needs of our students and faculty members. We have translated part of our web site into English, see http://www.seg.etsmtl.ca/ti/English/, to give you an idea of the work that was accomplished; figure 2 is a screen shot of the welcome page.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File Edit View Go Communicator Help
Bookmarks Location: http://www.seg.etsmtl.ca/ti/English/english.html
Back Forward Reload Home Search Netscape Print Security Shop Stop
TI-89 et TI-92 Plus Symbolic Hand-held Calculators at ETS
Welcome
FAQ
Links
Guided Tour
Documents
Contributions
Courses at ETS
Credits
Welcome to our web site at the École de technologie supérieure (ETS) in support of the use of the symbolic calculators,
TI-89
and TI-92 Plus
, from Texas Instruments (Warning!)
Since the 1999 fall semester, the TI-92 Plus or TI-89 has been a compulsory purchase for new students entering our engineering school. Our students learn to use these calculators in their first mathematics course (Calculus)
The purpose of this web site is to provide efficient support to the TI-92 Plus and TI-89 users. It is also intended as a centre for posting and retrieving useful programs created for specific courses at ETS. As you browse through this site, you will find many examples of mathematics problems that are solved using the symbolic capabilities of the calculators
Best viewed at a resolution of at least 800 by 600
Do not hesitate to contact us if you have any remarks or suggestions
The team at Service des enseignements generaux
Last update: May 28, 2001
Document Done

figure 2

The questions that we collected were classified into two groups. If a short answer was all that was necessary, it was put in the **FAQ** section. For instance, *How do I stop a calculation?* is listed in the FAQ. If the question demanded a more detailed explanation, such as *How do I solve a system of equations?* or *How do I enter and use matrices?* it was put in the **Documents** section of our site.

Another aspect of our experience was extending the use of these calculators to more courses at our university. We met with interested professors from the four engineering departments to present the calculator's potential, gave workshops, and informed them that their students had this technology at hand. To help stimulate discussion about this technology within the departments, and the changes it would inevitably bring to teaching, we hired four students, one per department, to work on small TI application modules. Each of these modules was designed to meet the needs of one or two courses in each of the four

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departments. For example, under the supervision of two professors from the Civil Engineering department, a student produced the links associated to **CTN-208** and **CTN-408** (courses on Analysis of Structures and Mechanics of Materials) in the **Courses at ETS** page of our site. His job was to write a set of TI programs and or commands that can be downloaded from our site onto the TI-89/92 Plus. He also had to produce the corresponding user's guide. Now, CTN-208 and CTN-408 students download these files to their TIs and use them in these courses.

Conclusion

As the introduction of this hand-held technology forced us to re-assess our goals in teaching mathematics, it also stimulated many discussions among faculty members. What do we want our students to learn? What is important? In particular, what should students still be able to do manually?

The hands-on approach made available by this technology makes for a more dynamic classroom as the students participate more actively in the exploration of mathematical ideas. We see using the available technology as one way to help students learn.

So far the results have been positive, students and most of our mathematics instructors are adapting to this new technology. There's still resistance from some faculty members and we must continue to put forward the benefits of integrating computer algebra in our teaching.

Acknowledgments We wish to thank Claude Pineau for proofreading this paper. Thanks are also due to Michel Beaudin and Chantal Trottier for their assistance in designing the web site www.seg.etsmtl.ca/ti/.

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